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Low evapotranspiration enhances the resilience of peatland carbon stocks to fire

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Highlights:

1. Low evapotranspiration from feather moss peatlands following wildfire.
2. Low evapotranspiration observable at landscape scale through concomitant high surface temperature.
3. Water repellency may act as an important, previously unidentified, control on peatland water loss via evaporation.

Abstract

Boreal peatlands may be vulnerable to projected changes in the wildfire regime under future climates. Extreme drying during the sensitive post-fire period may exceed peatland ecohydrological resilience, triggering long-term degradation of these globally significant carbon stocks. Despite these concerns, we show low peatland evapotranspiration at both the plot and landscape scale post-fire, in water-limited peatlands dominated by feather moss that are ubiquitous across continental western Canada. Low post-fire evapotranspiration enhances the resilience of carbon stocks in such peatlands to wildfire disturbance and reinforces their function as a regional source of water. Near-surface water repellency may provide an important, previously unexplored, regulator of peatland evapotranspiration that can induce low evapotranspiration in the initial post-fire years by restricting the supply of water to the peat surface.

1. Introduction

Peatlands represent a global climate regulator and a regionally important water resource, containing one-third of the global soil carbon pool [*Turunen et al*., 2002] and accounting for 10% of global surface fresh water [*Holden*, 2005]. Wildfire represents the largest disturbance to boreal peatlands, burning almost 1500 km^2 yr^{-1} and releasing 6,300 Gg C yr^{-1} within Western Canada alone [*Turetsky et al.*, 2002]. However, peatland carbon stocks are generally resilient to wildfire [*Weider et al.,* 2009]. Despite acting as a net carbon source in the initial years after fire, peatlands return to a net carbon sink and begin to offset the carbon lost during wildfires within ~20 years of the disturbance [*Weider et al*., 2009]. This resilience over multiple fire cycles arises from a complex array of negative ecohydrological feedback mechanisms that secure peatland carbon stocks under waterlogged conditions and promote the establishment and growth of keystone moss species [*Waddington et al*., 2015; *Johnston et al*., 2010]. However, changing climatic conditions are projected to induce drying across the Boreal [*Walker et al.*, 2015], increasing the severity [*Turetsky et al.*, 2011], extent and frequency [*Flannigan et al*., 2005] of wildfires. Such an alteration to the boreal fire regime may exceed peatland ecohydrological resilience of carbon stocks [*Kettridge et al*., 2015b], resulting in their long-term degradation, and providing a critical positive feedback to changing climatic conditions. As a result, there is an urgent need to identify and understand the key negative feedback mechanisms that regulate the resilience of peatland carbon stocks to wildfire, which have enabled these ecosystems to persist for millennia.

Evapotranspiration (ET) is the dominant water loss mechanism from boreal peatlands [*Lafleur et al*., 2005; *Petrone et al*., 2007; *Brown et al*., 2010]. The change in ET as a result of wildfire therefore provides the primary control on the ecosystem's capability to maintain the near-saturated conditions necessary to promote recovery [*Schouwenaars*, 1988]. Following wildfire, transpiration is substantially reduced due to the loss of vascular vegetation [*Amiro*, 2001]. Model simulations suggest that these reductions across the Canadian boreal are largely offset by increased sub-canopy evaporation [*Bond-Lamberty et al*., 2009]. Further, within *Sphagnum* dominated boreal peatlands, post-fire ET can exceed pre-fire ET [*Thompson et al.,* 2014]. Canopy removal increases both the energy availability [*Kettridge et al*., 2012; *Thompson et al*., 2015] and the potential ET within the sub-canopy [*Plach et al*.; 2016]. Within *Sphagnum* dominated peatlands the sub canopy can account for up to 80% of pre-fire ET [*Gabrielli*, 2016; *Lafleur and Schreader*, 1994]. This may enhance peatland drying in the initial years following wildfire [*Thompson et al.*, 2014] when ecosystems are sensitive to perturbation [*Kroel-Dulay et al.*, 2015]. However, continental boreal regions are dominated by water limited peatlands dominated by feather moss [*Natural Regions Committee*, 2006]. Whilst ET from peatlands dominated by feather moss are comparable to *Sphagnum* systems [*Kettridge et al*., 2012], their post-fire ET are unknown.

Substantial reductions in peatland evaporation due to drying have been observed under laboratory conditions [*Kettridge and Waddington*, 2014] and are incorporated in peatland hydrological simulations [*McCarter and Price*, 2012; *Kettridge et al*., 2015a]. Reductions in evaporation are triggered by low near-surface hydraulic conductivities that limit upward capillary flow under periods of drying [*Aluwihare and Watanabe*, 2003;

McCarter and Price, 2012]. Water repellency may also reduce evaporation, as evidenced by laboratory-based sand column experiments [*Shokri et al*., 2009], because it causes a hydraulic disconnect and/or a reduction in the capillary driving force between the soil water store and surface [*Shokri et al*., 2008]. Given that water repellency is observed in burned organic soils and peat [*O'Donnell* et al., 2009; *Beatty and Smith*, 2013], notably within feather moss peat [*Kettridge et al*., 2014], it may counteract enhanced post-fire drying, providing an important restriction on peatland ET.

Post-fire sub canopy ET (ET_{sc}) has not been observed within feather moss peatlands, despite their dominance across continental boreal regions and their functional role as global carbon stock and boreal head water sources [*Devito et al*., 2017]. For this reason, we directly measure post-fire ET_{sc} at the plot scale within a feather moss dominated peatland that may be vulnerable to post-fire drying. Furthermore, we expand this examination of ET_{sc} to the landscape scale, across multiple peatlands. We couple remote sensing with the dependence of high peat surface temperature on low ET_{sc} [*Kettridge et al*., 2012], recognizing that if ET_{sc} is low because the water supply to the surface is impeded then evaporative cooling of the surface is reduced, resulting in high surface temperatures. We determine how ET_{sc} responds to the high evaporative demand post disturbance and consider: i) the ecological and hydrological controls that regulate this primary water loss mechanism and ii) the implications of this response to the ecohydrological resilience of these carbon rich landscapes.

2. Methods

2.1 Study site

Field measurements were conducted within a peatland located on a coarse-textured outwash plain [*Smerdon et al.*, 2005; *Lukenbach et al.*, 2015, 2016] within the Utikuma Region Study Area (URSA), north-central Alberta (56.107^{o}N 115.561^{o}W). Prior to fire, the study site had a dense black spruce tree canopy (stem density of approximately 7,000 stems per hectare). The peatland burned in May 2011 during the ~90,000 ha

Utikuma complex forest fire. The fire resulted in complete mortality of above ground biomass. We classified the central portion of the peatland into two dominant surface covers based on the vegetation communities [*Lukenbach et al*., 2015]. The first microhabitat was dominated by feather moss (*Pleurozium schreberi*; 73% coverage [*Lukenbach et al*., 2015]). Combustion of the feather moss microhabitat occurred to a depth of 0.02 ± 0.01 m [*Lukenbach et al*., 2016]. The second microhabitat was dominated by *Sphagnum* (*Sphagnum fuscum*; 19 % coverage [*Lukenbach et al*., 2015]), which remained largely intact following the wildfire, with only slight observable combustion (singeing) of the peat surface (*Sphagnum* capitula intact) [*Lukenbach et al*., 2016].

2.2 Plot scale sub-canopy evapotranspiration measurement

ET_{sc} was measured at three representative locations within each microhabitat every hour between May and August 2012, one year after the fire, using Perspex® chambers (surface area, 0.2 m^2; volume ~0.05 m^3). Each chamber closed for two minutes each hour, during which the air within the chamber was continuously mixed by a fan. ET_{sc} at each measurement time was calculated from the rate of increase in humidity within the closed chamber (ACS-DC; Licor LI-840) [*cf Kettridge and Waddington*, 2014; *McLeod* et al. 2004]. The controls of the different microhabitats on daily ET_{sc} were analyzed using a general linear model [*R Core Team, 2016*] with the zone as a fixed effect and the chamber as a random effect to account for the lack of independence among collar measurements. Surface temperature was measured every hour within each chamber using a type-T thermocouple inserted just below the moss/peat surface. Leaf area index (LAI) was determined for each chamber throughout the growing season from the classification of digital images of the chambers [*Kettridge and Baird*, 2008], and at the end of the growing season (August 2012) using the leaf count approach [*Strack et al*., 2004]. Stomatal conductance of three leaves on three plants of each species within each chamber was measured where available using an AT4 Delta-T porometer. In combination with measured LAI, the stomatal conductance was used to calculate the proportion of ET_{sc} lost via evaporation (see S.1).

In early June 2013, two years after fire, ET_{sc} was measured at a further 37 locations (18 feather moss, 19 *Sphagnum*) across the full extent of the peatland during a period of high potential evaporation: humidity = 25.8 ± 6.0% (average ± standard deviation); air temperature = 29.8 ± 2.7 ^{o}C. ET_{sc} was measured using a mobile chamber system equivalent to the automatic system described above (PP systems EGM-4 infrared gas analyzer, chamber dimensions: diameter 0.3 m, height 0.5 m). Following ET_{sc} measurement, water repellency was measured at each location at a depth of 0.02 m (i.e., the zone within the moss/peat profile of extreme water repellency [*Kettridge et al*., 2014]) using the water drop penetration test (WDPT). This approach is used widely to characterize and compare the persistence of soil water repellency [*Doerr*, 1998; *Dekker et al.*, 2000; *Letey*, 2001] and involves measuring the time taken for a water droplet placed on the surface to infiltrate completely. Water repellency was determined from the classification of five water drops applied at separate positions within each chamber area. Each water drop location was classified as hydrophilic (<5 s), slightly hydrophobic (5-60 s), strongly hydrophobic (60-600 s) or severely hydrophobic (>600 s) [*Dekker* et al., 2000]. The water drop penetration time of each plot was taken as the average of the five discrete water droplet classes applied.

2.3 Thermal remote sensing and landscape classification

Remotely observed surface temperatures have been used widely to derive ET [*Fisher et al.*, 2017]. However, direct calculation of ET can be difficult [*Zhang et al*., 2016]. Small variations in surface temperatures (<1^{o}C) result from numerous controls that vary in response to fire [*Rocha and Shaver*, 2011]. Detailed simulations of adjacent burned and unburned peatlands (<40 km from the study site) examined the magnitude of different controls on peat surface temperatures; notably, differences in microclimate, moisture content, vegetation cover, albedo, surface roughness and potential difference in ET_{sc} were the primary controls [*Kettridge et al*., 2012]. The impact on peat surface temperatures of these above differences were limited; the compound impact of these variations increased maximum surface temperature by only 2.3 ^{o}C [*Kettridge et* *al*., 2012]. In comparison, reducing ET_{sc} to zero increased simulated surface temperature by >6^{o}C more than a freely evaporating peat surface. Therefore, only low/near-zero ET_{sc} can induce substantial increases in peat surface temperatures. Surface temperature of peat can thus be used to differentiate between regions in which ET is occurring freely and areas in which ET is severely restricted. This capability maps directly onto i) the bimodal nature of laboratory measures of peat evaporation (peat cores demonstrate rapid transitions in evaporation when threshold drying is exceeded [*Kettridge and Waddington*, 2014]), ii) the bimodal ET applied in peatland modelling studies [*Kettridge et al*., 2015a; *McCarter and Price*, 2012] and iii) the characteristic transitions between stage I and stage II evaporation for soils more generally [*Or et al.*, 2013].

To classify landscape-scale peatland ET, Airborne LiDAR (Light Detection and Ranging) and forward-looking thermal FLIR digital imagery (FLIR Inc. S60, Boston, MA, USA) were captured from an aircraft between 16:00 and 16:30 on August 12, 2011, approximately three months after the wildfire. Measurements were taken during clear conditions (Figure S.1), with an air temperature of 25 ^{o}C, relative humidity of 34% and average wind speed of 2.0 m s^{-1} (recorded at an adjacent unburned peatland) [*cf*. *Thompson et al*., 2014]. Four adjacent and overlapping flight lines of approximately 800 m width were flown for FLIR imagery, covering 40 km^2 across the region, with measurements obtained at a ground sample spacing of ~1.3 m along and across track. Of this region, 8.7 km^2 was burned as part of the Utikuma Complex forest fire. The thermal imaging used the infrared range of the electromagnetic spectrum, quantifying skin (surface) temperatures from the amount of radiation emitted from the surface in accordance with Stephan-Boltzman Law. Measurements assumed a black body with emissivity equal to 0.95, which is the emissivity of wet soil [*Weast*, 1986]. Thermal imagery was linearly ramped from 10 to 50 ^{o}C and manually georegistered to the corresponding LiDAR imagery and resampled to 1 m x 1 m pixel resolution following methods first described in *Hopkinson et al.* [2010]. Wetland and forestland areas were classified by *Chasmer et al*. [2016] from LiDAR images obtained prior to the fire.

3. Results

ET_{sc} of burned feather moss (0.63 + 0.27 mm day^{-1}) was significantly lower than that of burned *Sphagnum* (3.03+ 0.13 mm day^{-1}) (Figure 1a; df = 4, t = -22.32, $p < 0.001$). The lower ET_{sc} of feather moss throughout the day (Figure 1b) was associated with daily maximum surface temperatures more than 20 ^{o}C greater than the surface temperature of *Sphagnum* (Figure 1c). The LAI was low within *Sphagnum* chambers (*Ledum groenlandicum* and *Vaccinium oxycoccus*), increasing from an average of 0.22 to 0.45 over the measurement period (May to August). Given these values, evaporation accounted for between 55% and 78% of ET_{sc} in the *Sphagnum* chambers through the growing season (see S.1). Within the feather moss chambers, there was no leaf cover. Therefore, ET_{sc} was entirely attributable to evaporation.

Across the peatland, between 11:00 and 16:00 on a day of high evaporative demand, ET_{sc} varied between -0.008 (dewfall) and 0.17 mm hr^{-1} (μ = 0.038 mm hr^{-1}, standard error = 0.0058 mm hr^{-1}, n = 41). During this period (i) ET_{sc} ($p < 0.0001$, Z = -4.892, n = 37), (ii) surface temperature ($p < 0.001$, F = 5.202, n = 37) and (iii) mean water drop penetration time at a depth of 0.02 m ($p < 0.0001$, Z = -5.318, n = 37), all differed significantly between burned *Sphagnum* and feather moss microhabitats. All *Sphagnum* microhabitats were hydrophilic. Feather moss plots were predominantly strongly hydrophobic (78%), with a small proportion classified as severely hydrophobic (17%) and slightly hydrophobic (6%).

Average surface temperatures of the previously treed and non-treed peatland areas within the fire perimeter were 11 ^{o}C higher than outside the fire perimeter (Figure 2). Outside the burn, mean surface temperature within the treed and non-treed peatland area averaged 23 ± 4 ^{o}C (± standard deviation). Within the perimeter, treed and non-treed peatland surface temperatures averaged 34 ± 10 ^{o}C. These high surface temperatures within the burned region strongly suggest that the low post-fire ET_{sc} observed over time within the auto chambers and across the peatland from the roving chamber measurements, are evident at the landscape scale across multiple peatlands within the burn scar. It is not currently feasible to confidently classify the subsurface micro habitats from post fire remote sensing imagery and thus to directly compare temperatures between feather moss and *Sphagnum* micro habitats at the landscape scale.

4. Discussion

4.1 Cross-scale post-fire sub-canopy evapotranspiration

Differences in post-fire ET_{sc} between feather moss and *Sphagnum* microhabitats are stark and are far in excess of differences observed previously within unburned peatlands (Figure 3a; [*Heijmans et al*., 2004; *Brown et al*., 2010; *Kettridge et al*., 2013]). Average post-fire *Sphagnum* ET_{sc} is similar in magnitude to previous studies. Concurrently, ET_{sc} from feather moss microhabitats is lower than any previous peatland study, including those in which the vascular vegetation cover is removed reducing transpiration to zero [*Heijmans et al*., 2004]. As a result, the ratio between *Sphagnum* and feather moss ET_{sc} was equal to 5.0, three times that of the unburned sites (Figure 3b). Further, this ratio was even higher (8.1) under a period of extreme evaporative demand during the spatial survey. The response of the peatland sub-canopy thus appears to show a diverging pattern in response to fire, with post-fire ET_{sc} from *Sphagnum* microhabitats being largely maintained, and ET_{sc} from feather moss microhabitats reducing to rates equivalent to black spruce boreal forests above a mineral soil [*Heijmans et al*., 2004].

Post-fire ET can exceed pre-fire losses in *Sphagnum* dominated-boreal peatlands (Figure 4) [*Thompson et al.*, 2014]. Pre-fire, feather moss peatland ET is similar to *Sphagnum* dominated ecosystems [*Kettridge et al*., 2012]. However, ET within these ecosystems is reduced substantially post-fire due to the loss of tree transpiration and the inability of the burned feather moss sub canopy to respond to the increased evaporation potential (Figure 4). Elevated surface temperatures in the burnt peatland areas of the remotely surveyed region highlight the wide spatial extent of this low post-fire ET at the landscape scale. Whilst complex feedback mechanisms regulate near-surface soil temperatures [*Kellner et al.*, 2001; *Kettridge and Baird*, 2010], only near-zero ET can induce the high surface temperatures observed [*Kettridge et al.*, 2012]. Where the remote sensing was undertaken, wetlands accounted for 47% and 60% of the land surface area within the till moraine and clay plain hydrogeological settings, respectively [*Chasmer et al*., 2016]. Therefore, low post-fire ET within feather moss peatlands not only influences the ecohydrological function the individual wetlands, but also has the potential to result in large-scale transitions in water conservation within the western boreal plain; with such peatlands acting as regional scale head water sources in the sub-humid climate of the Boreal Plains [*Devito et al*., 2017].

The dominance of peatland communities varies widely among peatlands driven by differences in climate, hydrogeology [*Devito et al*., 2005], age [*Benscoter and Vitt*, 2008], disturbance regime [*Turetsky et al*., 2012] and recovery period [*Benscoter and Vitt*, 2008; *Lukenbach et al*., 2016]. *Sphagnum* dominated systems, where increased evaporation may exceed small reductions in tree transpiration post-fire (Figure 4) [*Thompson et al.*, 2014], tend to be wetter and deeper peatlands with larger water and carbon stocks available to endure discrete disturbances. In comparison, feather moss dominated peatlands are associated with low available light, shallow peat depths and deeper water table positions [*Bisbee et al*., 2001]. Importantly, these drier peatland systems with higher pre-fire tree transpiration and limited carbon stocks will likely show a strong negative feedback response to fire, with both reduced ET_{sc} and tree transpiration post-disturbance (Figure 4).

4.2 Controls on post-fire sub-canopy evapotranspiration

The extreme contrast in post-fire ET_{sc} between *Sphagnum* and feather moss microhabitats results, in part, from the lack of recovery of vascular vegetation within the feather moss microhabitats and thus the low sub-canopy transpiration. Despite that, ET_{sc} remains lower than in manipulation experiments in which the vascular vegetation is removed [*Heijmans et al*., 2004] (Figure 3), with the exposed moss unable to meet the high post-disturbance potential evaporative demand [*Kettridge and Waddington*, 2014; *McCarter and Price*, 2014]. Even under high post-fire evaporative demand, *Sphagnum* profiles maintain connectivity with subsurface water stores. In comparison, within the study site, a severe disconnect occurs between the burned feather moss surface and saturated water stores just 0.33 m below [*Lukenbach et al*., 2016]. This results from the nature peat moss structure which unlike *Sphagnum* does not have an effective external wicking system along the moss surfaces [*Callaghan et al*., 1978] and the low moisture content observed at the study site within the near-surface of the peat [*Lukenbach et al*., 2016]. Lower water contents reduce the unsaturated hydraulic conductivity, which limits the supply of water to the peat surface, leading to further drying of the near-surface [*Waddington et al*., 2015; *McCarter and Price*, 2014]. Here, we hypothesize that this feedback response is further enhanced by the water repellent nature of the feather moss profile, induced by drying and enhanced by fire [*Kettridge et al*., 2014].

Water repellency is more severe under dry conditions and can arise from bonding of organic substances to soil particles because of the temperatures experienced during the wildfire [*Doerr et al*., 2000]. Thus, the low moisture content in the near-surface of the burned feather moss induces water repellent conditions. A severely hydrophobic layer is observed at a depth of 0.02 m, and extends between a depth of 0.01 and 0.07 m with a slightly hydrophobic layer above and a hydrophilic layer below [*Kettridge et al*., 2014]. The direct control of this water repellent layer on water transport through the peat profile is not certain. Further, the codependence of evaporation, water repellency, hydraulic conductivity and moisture content prevents the direct control of water repellency on evaporation being defined here. This may be examined within future research in which the water repellent nature of moss species is altered by without impacting the soil structure. Within laboratory-based sand columns experiments such an approach has shown water repellency to substantially reduce evaporation, causing a hydrological disconnect and/or reduction in the capillary driving force between the soil-water store and the evaporation surface [*Bachmann et al*., 2001; *Shokri et al*., 2008]. The water repellent layer may accordingly act as a figurative one-way valve, permitting rainfall to percolate down through preferential flow pathways to the water table beneath because of the high porosity of the peat and the abundance of macro pores [*Holden*, 2009], but restricting its loss via evaporation at local and regional scales [*Rye and Smettem*, 2017]. Such a feedback response would limit peatland evaporation during periods of high solar radiation resulting from the burning of the shrub and canopy cover [*Thompson et al*., 2015]. Whilst water repellency in the studied peatland persisted for at least two years, depending upon site conditions, water repellency can remain for of several years [*Doerr et al.*, 2000]. Water repellency therefore has the potential to conserve water during this period, protecting the peatland until a shrubs and canopy cover increases shading and reduce evaporative demand.

5. Conclusion

Sub canopy evapotranspiration (ET_{sc}) is a critical determinant of peatland carbon stock vulnerability to wildfire and has the potential to influence landscape-scale transitions in water availability. Despite increased energy availability due to the open post-fire canopy and increased turbulent exchange from the sub-canopy post-fire, feather moss ET_{sc} was extremely low, equivalent to rates observed within a black spruce boreal forests above a mineral soil. Thus, rather than counteracting post-disturbance reductions in tree transpiration from the canopy, ET_{sc} enhances such reductions in systems dominated by feather moss (Figure 4). Reduced ET_{sc} results from the poor recovery of the sub-canopy vascular vegetation cover and the hydraulic disconnect of the surface from the saturated peat just decimeters below. The latter is likely due to the low hydraulic conductivity of the dry near-surface peat and the severely hydrophobic nature of the post-disturbance feather moss peat. Moreover, low post-fire ET was evident at the landscape scale. Thus, shallow water tables and associated near-saturated conditions will be maintained across the burned regions, protecting boreal peat by reducing decomposition rates [*Waddington et al.*, 2015] and increasing the resilience of their carbon stocks to disturbance over multiple fire cycles. Further it will enable peatlands to act as important post-fire water sources within boreal landscape.

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Figures

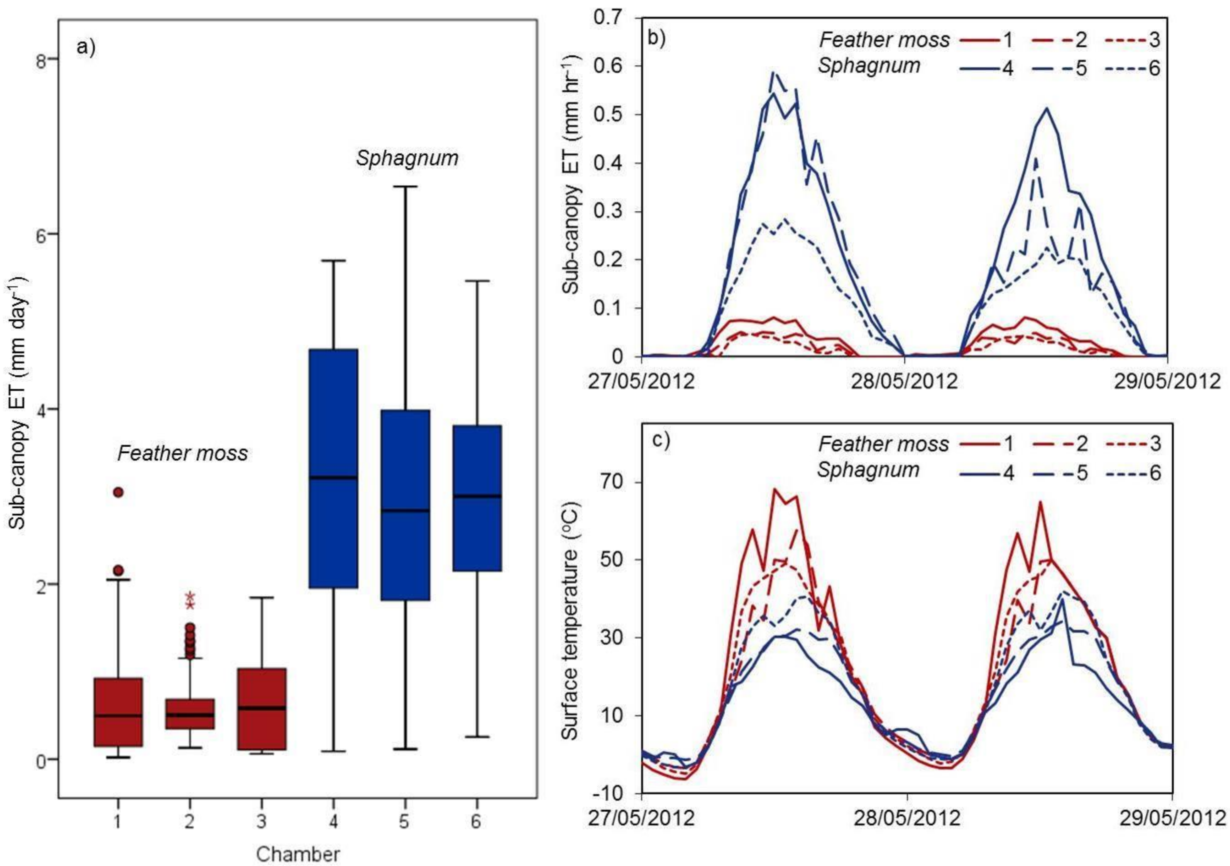

Figure 1: a) Distribution of median (total) daily sub canopy evapotranspiration measured in six auto chambers within burned feather moss and *Sphagnum* microhabitats for the entire measurement period. Diurnal fluctuation in b) hourly sub-canopy evapotranspiration and c) hourly surface temperature across two representative days for the six auto chambers.

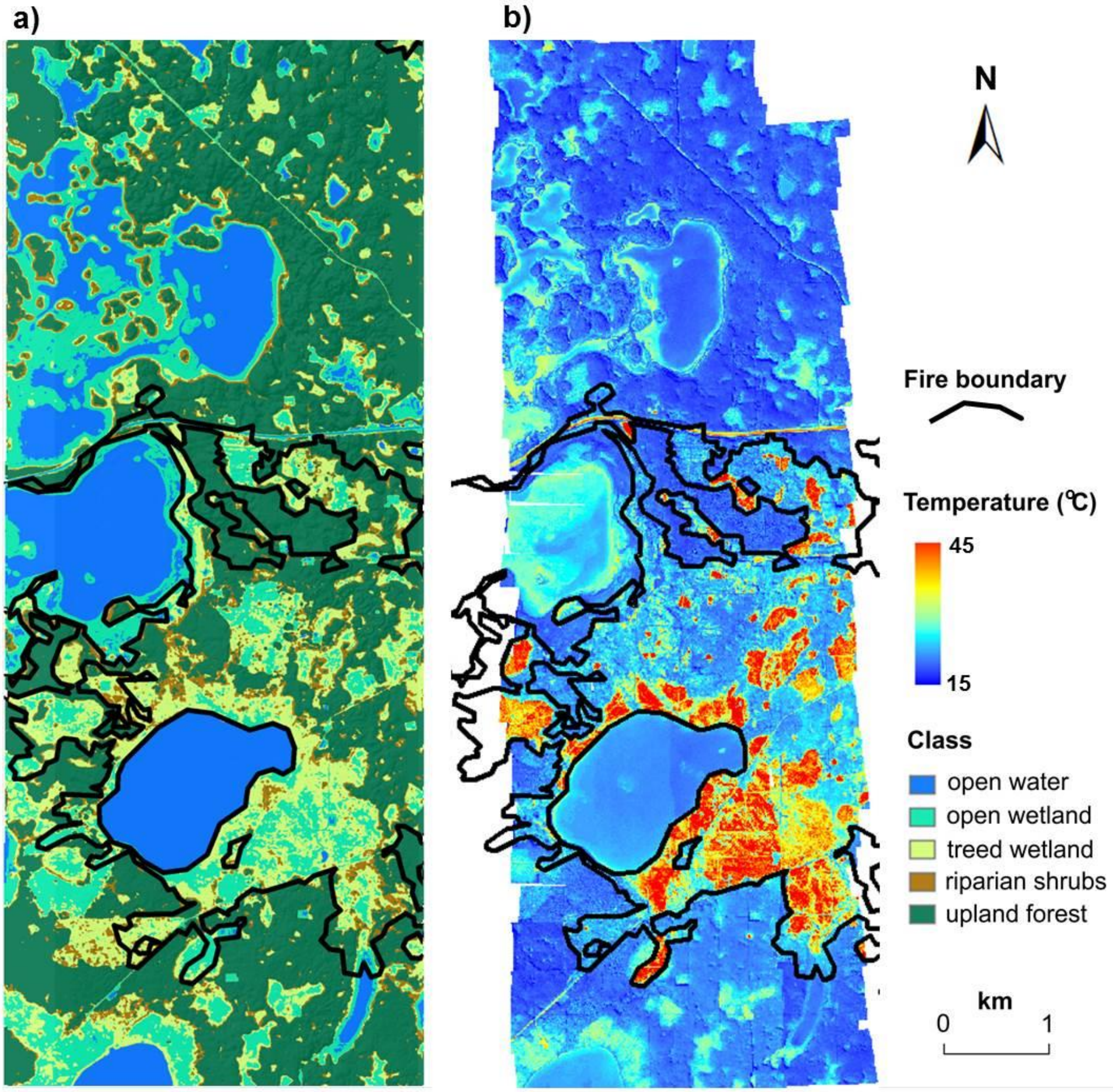

Figure 2: (a) Landcover classification (after *Chasmer et al*. [2016]) and (b) thermal image of remote sensing area. Burned area is within the solid black lines in lower half of images.

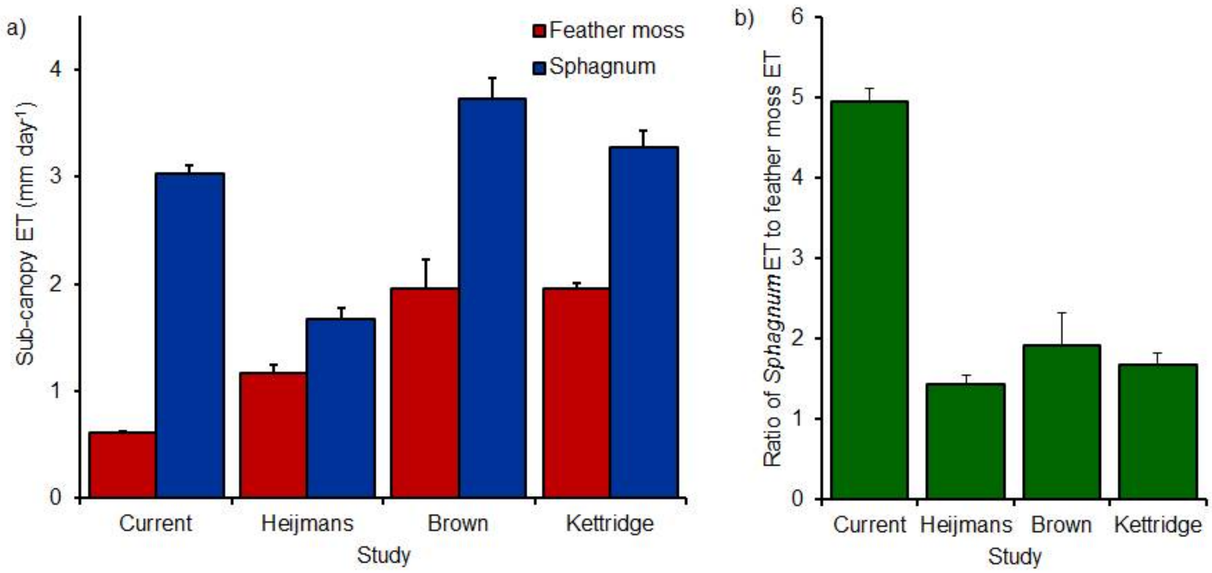

Figure 3: a) Sub-canopy evapotranspiration (ET_{sc}) from *Sphagnum* and feather moss microhabitats in the current study, and from the studies of *Heijmans et al.* [2004], *Brown et al.* [2010] and *Kettridge et al.* [2013]. b) Ratio of *Sphagnum* and feather moss ET_{sc} presented within a). *Sphagnum* communities consist of *S. fuscum* only in the current study and the study of *Kettridge et al.* [2013]. *S. fuscum* dominates *Sphagnum* microhabitats in *Heijmans et al.* [2004] and *Brown et al.*, [2010]. However, *S. cappilfolium* is also present in microhabitats of *Brown et al*, [2010] and *S. cappilfolium* and *S. magellanicum* are present in micro habitats of *Heijmans et al*. [2004]. ET_{sc} is measured diurnally within the current study and in *Heijmans et al.* [2004]. Within *Brown et al.* [2004] and *Kettridge et al.*, [2013], ET_{sc} is measured between 10:00 and 16:00. Daily totals presented are calculated assuming the ratios with the current study are maintained over the entire diurnal cycle.

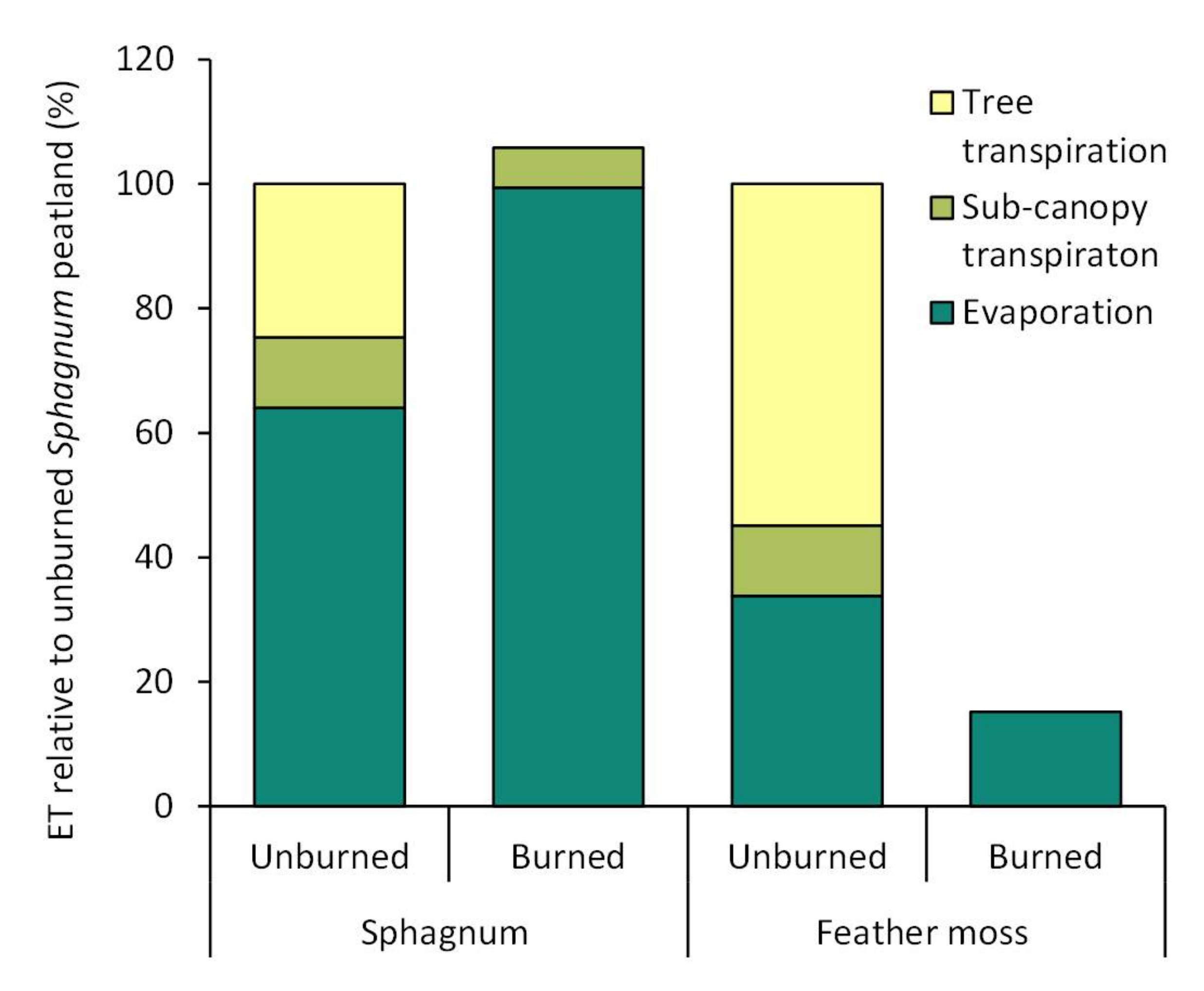

Figure 4: Evapotranspiration (ET) from burned and unburned *Sphagnum* and feather moss dominated peatlands and their associated components relative to ET from a *Sphagnum* dominated peatland. *Sphagnum* evapotranspiration fluxes were derived from *Thompson et al.* [2014]. Unburned feather moss ET equal to unburned *Sphagnum* peatland [*cf. Kettridge et al*., 2013]. Unburned feather moss sub-canopy evapotranspiration from *Heijmans et al.* [2004], *Brown et al.* [2004] and *Kettridge et al.*, [2013], with sub-canopy transpiration component assumed equivalent to the unburned *Sphagnum* peatland (Figure 3). Burned feather moss ET derived within this study.